Non-optical Imaging of Flow, Boiling, and Salt Deposition in a Simulated Debris Bed

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Neutron Imaging of Isothermal Debris Bed for Flow Visualization and Void Fraction Estimation

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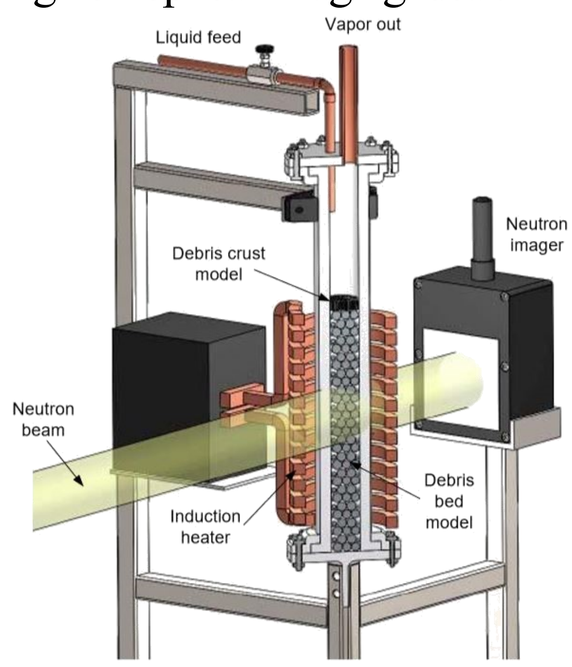
Nu-EST Lab

Debris Bed Cooling

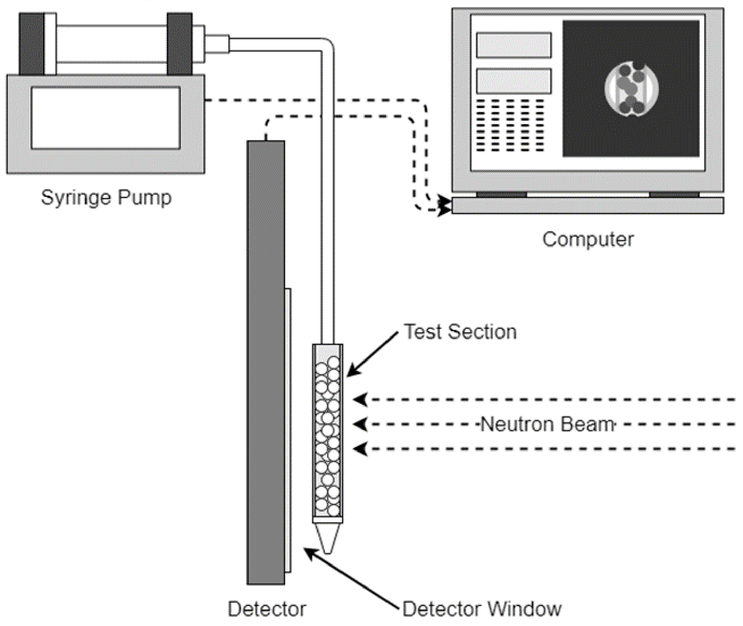
- Continuous decay heat removal is a critical need under severe accident at nuclear power plants.
- Effects of using seawater are not well understood.
- Lack of optical access in a packed bed makes visualization and analysis techniques difficult, making non-optical imaging ideal.



A-Si Imager

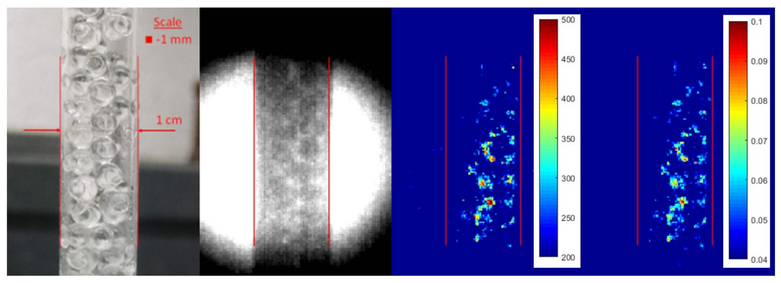
- Amorphous Silicon Flat Panel have high efficiency by avoiding loss of photons without any need for photo-multiplication.
- High speeds (up to 100 Hz) and high resolution (up to 100 μm) makes this ideal for two phase flow experiments.
- There is a need for verification for using this method in multi-phase flow experiments.

Experimental Setup



- Water has very high scattering cross section for thermal neutrons, providing the high contrast needed for visualizing water flow through solid beds.
- TRIGA Mk II. Beam port neutron source with a Perkin Elmer A-Si Flat Panel Detector
- Syringe pump infused 2.5 mL of water into top of the bed at flow rates from 2.5-10 mL/min

Image Analysis

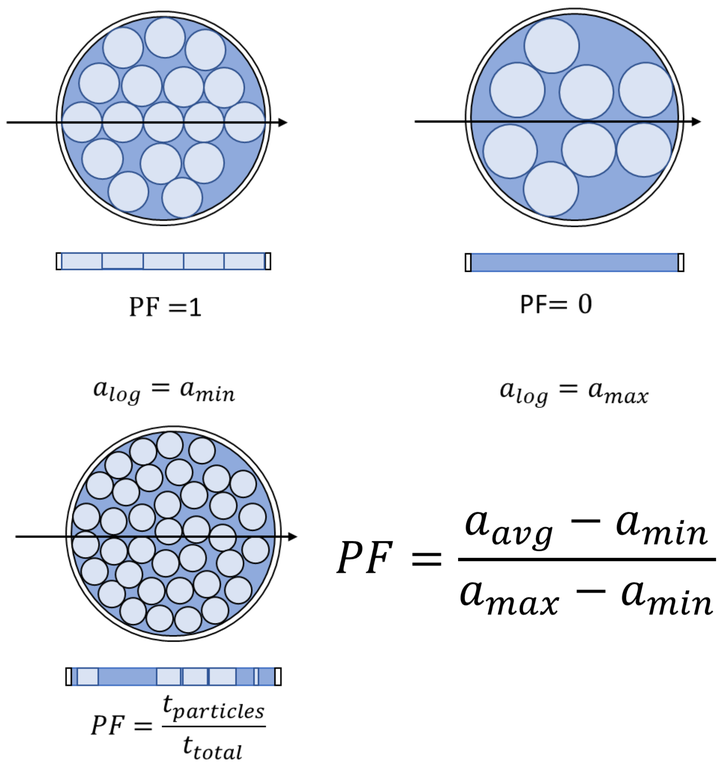


- Simple subtraction transform for basic visualization.
- Logarithmic transform to account for exponential attenuation through material was used for numerical analysis.

$$b_{log} = -\log\left(\frac{a}{a_B}\right)$$

Packing (Void) Fraction

- Packing fraction estimated by fill and drain process of .52+/-.005
- Packing fraction can be estimated by analyzing neutron images-from linear relationship between the log transform pixel values and material thickness.
- Packing fraction calculated for constant test section thickness and averaged.

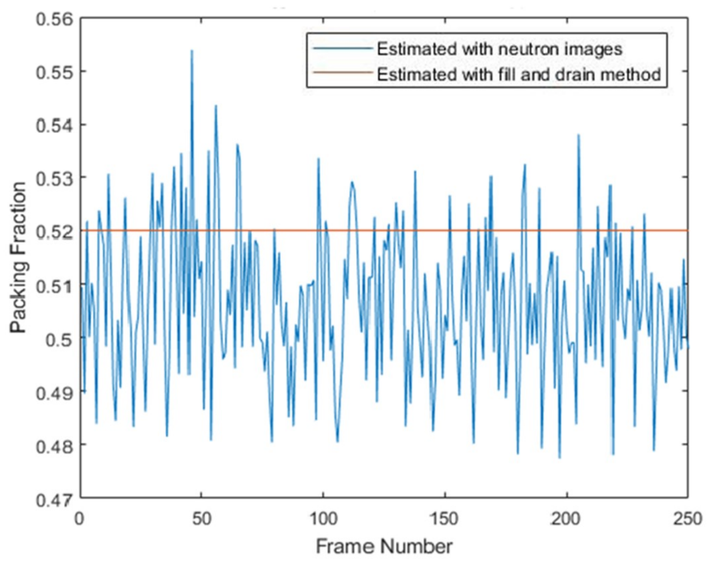


$$PF = \frac{a_{avg} - a_{min}}{a_{max} - a_{min}}$$

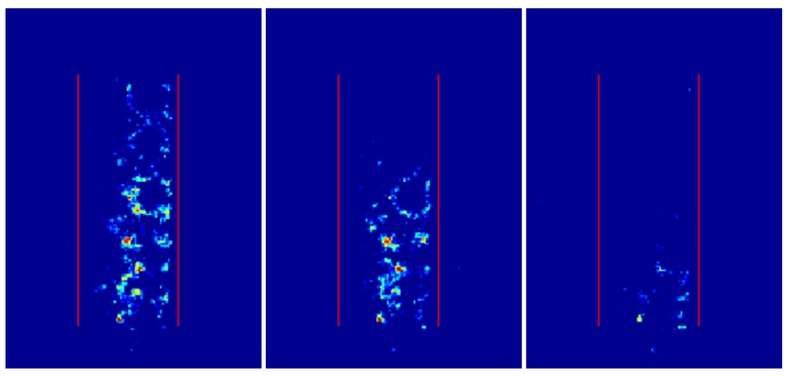
$$PF = \frac{t_{particles}}{t_{total}}$$

$$a_{log} = PF(a_{max} - a_{min}) + a_{min}$$

- Packing fraction estimated from neutron imaging~ 0.52+/-.03.



Flow Rate measurements



- Sum of pixel values of log transform correlate to volume of water.
- Multiply volume of water in largest section by ratio of the sum of pixel values in largest section by a frame to get volume of water in that frame

$$V_{max} = .25\pi D_{in}^2 (PF) hC$$

$$V = V_{max}\frac{\sum a}{\sum a_{max}}$$

- Calculated experimental flowrate is obtained by taking the change in flow rate between frames over the change in time between frames.

$$\frac{\partial V}{\partial t} = \frac{V_{n+1} - V_n}{t_{n+1} - t}$$

- Experimental flow rate for purely draining was 3.25+/-.59 mL/min.
- Theoretical flow rate from $v=A\sqrt{2gh}$ was calculated to be between 3.1 and 3.7 mL/min.
- Same procedure was followed for time when syringe pump was on.
- Theoretical flow rate for infusion and draining was 6.6+/-.4 mL/min.
- Experimental flow rate for infusion and draining was 6.25+/-.88 mL/min.

Conclusions

- Neutron imaging coupled with the provided image analysis techniques provides an accurate method to visualize and measure packing fraction and flow rates in a packed bed.
- The log transform is an effective method to estimate the macroscopic quantities, but in future work, more advanced image characterization tools will be deployed.

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